AN APPLICATION OF SIDE-TONE IN SUBJECTIVE TESTS OF MICROPHONES AND HEADSETS

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SUMMARY

The speaker in a microphone-headset system monitors his vocal sound pressure level through his side-tone. This feedback is affected by the frequency response of the communication circuit including the end pieces: the microphone and headset. The side-tone provides the basis to which the speaker attempts to adjust the level of his voice. Through the method of average error an experimental determination was made of the relative vocal level that attended broad-band and narrow-band side-tone channels as provided by alternative headsets and microphones. Preponderantly the speakers produced higher vocal levels when broad-band end pieces were in the circuits.

INTRODUCTION

The signal at the speaker's ear, that is, his side-tone when he himself is speaking into an aircraft intercommunication system, may be of the same level as the signal at the other headset positions in the circuit when he is the listener. This situation prevailed in the simulated intercommunication system of the present experiment. The side-tone or auditory feedback provides the principal signal by which the speaker monitors his level; apparently he tends to maintain an experience of loudness that he considers 'normal,' 'satisfactory,' or perhaps 'comfortable.' As side-tone is altered, voice level is varied inversely for example, an approximate ratio of 1 db of voice level to 6 db of side-tone attenuation (3). When temporary hearing loss or threshold shift is experienced the level of the voice is raised, and as normal hearing returns the level of voice is lowered (1). In a somewhat related manner, the level of the speaking voice is a function of the reverberation characteristics of the room, a dead room eliciting a higher sound pressure level of speech than a live room (2).

The tendency for a speaker to establish and maintain a 'normal' level of side-tone was the principal rationale for an exploratory study in which the operator's vocal responses to alternative microphone and headset combinations in the side-tone circuit were tested.

PROCEDURE

Twenty-four males, Naval Hospital Corpsmen with normal hearing who were undergoing a program of specialized training, served individually as experimental subjects. Each speaker, after producing a side-tone with either of two microphones and an HS-33 headset, was asked to re-establish or match this side-tone in level as a recording of it was fed to his ears intermittently and as he spoke the same phrase both with the original headset-microphone combination and alternative equipment. The experimental task and the treatment of the data were in keeping with the method of average error. The comparisons were made both in quiet and in 114 db of simulated aircraft noise--eight matching combinations. The experimental room was sound treated and had a reverberation time of 0.145 sec.

A single five-syllable phrase was spoken several times while the magnetic tape recorder in the circuit was adjusted to optimum recording level (Ampex model 400). One saying of the phrase was recorded on a loop of tape. Half of the subjects read the phrase over one microphone and half over the other. The single recorded signal was played back to the speaker ten times at three-second intervals, the playback system delivering the same voltage at the earphones as the original level of the side-tone of the speaker. With each replaying through the ten trials, the speaker attempted to match the level of his side-tone as he repeated the phrase to the constant level of the playback of the recorded stimulus. The relative levels of both the original recording and the 'matched side-tone' at the speaker's earphones were indicated on a power level recorder that was bridged across the circuit (Sound Apparatus Company; 50 db potentiometer; 50 mm/sec.).

The microphones used throughout these experiments were the hand-held service carbon microphone RS-38 which is described in the present comparison as narrow band, and a commercial condenser microphone, the Altec 21-B, described herein for purposes of comparison as broad band. Similarly the alternative headsets are referred to as broad band and narrow band, these instruments being respectively the military headset HS-33 with 'doughnuts' and a pair of Maico hearing aid receivers in earpieces that were individually fitted to the subjects' ears.

The mean value of three maximum excursions of the stylus of the graphic recorder in its response to the phrase was taken as a measure of the relative sound pressure level of a spoken phrase. Since the stimulus phrase that had been recorded for each speaker was played back ten times, the reliability of the combination of (a) the playback of the tape recorder and (b) the graphic recorder was readily obtained. The standard deviation of the 'phrase values' (mean of three peaks) was determined for each of 24 subjects. The median standard deviation of the 24 values was 0.5 db.

The combinations of headsets and microphones that were employed and the circumstances under which the recorded side-tones were matched were:

	QUIET		NOISE (114 db)	
	Microphone	Headset	Microphone	Headset
Combination 1	Narrow-band	Broad-band	Narrow-band	Broad-band
Combination 2	Narrow-band	Narrow-band	Narrow-band	Narrow-band
Combination 3	Broad-band	Broad-band	Broad-band	Broad-band
Combination 4	Broad-band	Narrow-band	Broad-band	Narrow-band

RESULTS

The mean difference (db) between the voltage level of the signal that was heard by the speaker and the matching side-tone that he produced was determined from the graphic level recordings. The means of these differences for the eight experimental conditions are enumerated in Table 1.

A positive entry in the table indicates that the matching side-tone was higher in level than the stimulus, and a negative value that the matching side-tone was 'low.' In six of the eight conditions the speakers generated more voice signal in the matching process than they thought they were producing. The maximum difference among the means of the responses that was presumably attributable to the equipment combinations amounted to approximately 5 db both in quiet and in noise.

Under the assumption that the distinguishing feature between the two microphones was band width, the comparison in Table 2 is indicated. This table shows the arithmetic difference between the obtained 'error values' or 'mis-matchings' that are listed in Table 1 and which pertain to different microphones and the same headsets. Thus, combination 3 (quiet) minus combination 1 = +2.19 minus (-0.72) = 2.91. The values in Table 2 indicate that in the quiet or 'better' listening condition the side-tone levels that 'matched' the stimulus signals were of greater pressure magnitude when the side-tone signal was transmitted by a broad-band microphone; in the noise condition the opposite circumstance obtained.

A comparison similar to the one described in the preceding paragraph is presented in Table 3 in which the entries are differences between headsets, with microphones constant. Thus, combination 1 minus combination 2 (quiet) = -0.72 minus (-2.53) = 1.81. In three of the four comparisons that are summarized in Table 3 the 'matched' side-tone levels were higher in level when the broad-band headset was in the system than when the narrow-band headset was in the system.

In three of the four combinations of equipment the magnitude of the error in establishing the level of side-tone in noise was greater than the comparable error in quiet. These differences can be observed through comparing the values within the rows of Table 1.

The arithmetic differences between the voltages (db) at the earphone of the heard and spoken signals were determined for the successive pairs of stimulus-response combinations. This procedure yielded 10 values for each speaker. These were arranged in a row with columns representing successive performances. There were twenty-four rows, each represented an experimental subject. Analysis of variance did not indicate a significant change in the stimulus-response relationship with successive performances. Thus, less than ten performances per individual might have been used. Also, this analysis would indicate that the speaker's adjustment to the level of response was apparently made rapidly.

DISCUSSION

In a closed system at the ear such as prevailed in this comparison the stimulus for the side-tone experience could arrive only through the headsets and through bone conduction, i.e. bone, tissue, etc. Moreover, in such a coupling the bone-conducted side-tone is typically amplified (4). Thus, there might be reason for supposing that internally transmitted side-tone would summate with the side-tone from the headset and that an illusory 'matched' level would be less intense physically than the stimulus signal.

The possibility remains that this occurs, particularly in quiet, in view of the inconclusive values in quiet of Table 1.

Although the difference between the two microphones relevant to the present comparison was presumably in their frequency response, the possibility must not be overlooked that consequent and secondary dissimilarities such as harmonic, phase, and amplitude distortion may have operated. The subjects could compensate for such differences as dynamic range and sensitivity to signal strength. The capacity of each microphone to match the stimulus signal was assured, the stimulus signal having been fed through each microphone by the speakers. (The matching process held the possibility for a 'time error,' the matching response always being made after the stimulus had been heard.)

Quiet. In quiet the broad-band microphone conveyed more level than did the narrow-band when the side-tone was 'matched' to the stimulus. Thus, when 'matched,' the narrow-band microphone delivered less sound pressure to the earphones than there 'should have been.' This average error could have been contributed by a bone-conducted component or by the distortion properties of the microphone. With the broad-band microphone (combinations 3 and 4, quiet) the speaker delivered more sound pressure to the ear than he supposed. Since the experimental condition was quiet, the 'error' pressure had to originate in speech, not in room noise such as entered the system in noise. By definition this microphone carried more high frequencies than the narrow-band microphone. A tentative explanation is that in addition to the side-tone stimulus for the monitoring of loudness--presumably much the same for the two microphones--the power of 'other' speech frequencies, higher ones, affected the meters and not the speaker-listener. Alternative explanations might include the possibility that the loudness-level function was affected by certain response peaks or other inherent properties of distortion.

Noise. The consistent 'over shooting' of the speakers under the noise conditions is apparent in the values of the right-hand column of Table 1. Possibly with the experimental task the speakers tended to mask competing noise. Alternatively the speaker may have gauged the proper level better than is indicated, and the room noise at the microphone may have accounted for his error. The better matching occurred with the broad-band microphone in the system.

Equipment. As a functional test of equipment the procedure outlined in this comparison provides a measure that may be of value. There is parallel performance between the broad-band microphone and headset, and between the narrow-band microphone and headset. In both of the quiet conditions and in one condition of noise the broad-band headset delivered more energy to the ear during a subjectively 'matched' circumstance than did the narrow-band receivers. From another view and particularly with respect to the quiet conditions, it is noteworthy that when all equipments appeared to be 'equally loud,' the broad-band microphone and headset were transmitting more power. The fact that the narrow-band equipments yeilded 'extra' loudness with less signal strength is not only in line with a frequency-response explanation but also with the common experience that distorted acoustic signals may appear to be more intense than they are.

CONCLUSION

The purpose of the present comparison was twofold. First, the direction and magnitude of the speaker's errors in evaluating his side-tone was under test. The tentative conclusion, independently of whether broad-band or narrow-band equipment was used, is that the speaker who is using an electrical communication system usually puts more external side-tone to his ear than he thinks he does. Second, the effect of equipment upon the judgment of side-tone level was under test. Without a priori knowledge and certainty of whether a broad-band microphone is superior to a narrow-band in military applications, there is at least reason to believe that the same general effects result from the band-width characteristics, whether narrow or broad, in either headsets, or microphones. Broad-band and narrow-band equipments lead to distinctly different evaluations of equal side-tone sound pressure level on the part of the human monitor. These results, in turn, are consistent with the subjectively observed association of a higher than actual sound level pressure judgment with the distortion characteristic of narrow-band equipment.

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TABLE 1

MEAN DIFFERENCE (db) BETWEEN THE SOUND PRESSURE LEVEL OF A HEARD PHRASE AND THE 'MATCHED' SIDE-TONE.

Trials per S, 10; Ss, 24.

	Microphone	Headset	Quiet	Noise
Combination 1	Narrow-band	Broad-band	-0.72	+5.91
Combination 2	Narrow-band	Narrow-band	-2.53	+3.94
Combination 3	Broad-band	Broad-band	+2.19	+0.99
Combination 4	Broad-band	Narrow-band	+1.08	+3.74

TABLE 2

MEAN DIFFERENCE (db) BETWEEN THE 'MATCHED' SIDE-TONE LEVELS WHEN THE SIDE-TONE WAS TRANSMITTED VIA A BROAD-BAND MICROPHONE AND WHEN IT WAS TRANSMITTED VIA A NARROW-BAND MICROPHONE. (BROAD-BAND MICROPHONE OF TABLE 1 MINUS NARROW-BAND FOR HEADSETS SEPARATELY.)

	Headset	Quiet	Noise
Combination 3 minus 1	Broad-band	2.91	-4.92
Combination 4 minus 2	Narrow-band	3.61	-0.20*

* Only the value 0.20 is not significant at the 5 per cent level of confidence.

TABLE 3

MEAN DIFFERENCE (db) BETWEEN THE 'MATCHED' SIDE-TONE LEVELS
WHEN THE SIDE-TONE WAS RECEIVED VIA BROAD-BAND AND NARROW-BAND HEADSETS.
(BROAD-BAND HEADSET OF TABLE 1 MINUS NARROW-BAND HEADSET
FOR MICROPHONES SEPARATELY.)

	Microphone	Quiet*	Noise*
Combination 3 minus 4	Broad-band	1.11	-2.75
Combination 1 minus 2	Narrow-band	1.81	1.97

* All values are significant at the 5 per cent level of confidence.